Optimization of Process Parameters for Material Removal Rate Kerf Width and Surface Roughness in Wire Cut Electrical Discharge Machining Process

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ABSTRACT

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. In this study, various machining conditions were investigated to determine the effect of process parameters on the process responses (Material Removal Rate, Kerf and surface roughness. MRR is greatly affected by T_{ON} than other factors and is less affected by TOFF according to ANOVA. For a given range, MRR is maximum at T_{ON} = 114 µs. According to ANOVA, there are no factors which greatly affect the Surface Roughness whereas T_{ON} may moderately affect it and IP will have almost no affect, Within a given range, SR is minimum at T_{ON} = 115 µs. Kerf width is likely to obtain for T_{OFF} at 58µs,Kerf width is not likely affected by peak current.

1. Introduction

The Wide usage of Titanium and its alloys is because of its excellent properties namely, high toughness, resistance to corrosion, high strength to weight ratio, long lasting durability material. The considerable issue in machining of titanium is the maximum precision and minimum machine time in all of its applicable fields such as, aerospace, automobile, electronics, medical fields etc. The past three decades, application of this material in medical and biomedical instruments has increased due to methods of new processing is introduced such as computer-aided machining and Wire Electrical Discharge Machining (WEDM).

An effective solution of machining is provided by WEDM process in a non-traditional method is difficult-to-machine materials. The quality of engineering parts and components is measured by surface roughness that is one of the machining factors. The huge heat generated during WEDM leads to the microstructure and material composition change and a layer of oxide produced on the machined material surface. Therefore, machining titanium with a high quality, smooth surface and high accuracy is a purpose for most of the industries and researchers. Numerous studies have been done on improving surface roughness and different methods were applied such as Data-Dependent System (DDS) that is used in this study. In addition, Material Removal Rate is another performance requirement that wire electrical discharge machine should satisfy it. Producing more work in less time is important for many industries and researches. On the other hand, WEDM process exhibits very slow cutting speed. Therefore, improving WEDM MRR and WEDM productivity is researcher’s purpose.

1.1 Literature

The metal Titanium offers an excellent fatigue resistance, high strength to weight ratio and good corrosion resistance which need to be maintained at elevated operating temperatures. In modern day industrial applications, the titanium and its alloys are very much attracted the researchers with its extra ordinary and unique properties which are stated in [1]. To evaluate the influences of process parameters on behaviour of titanium surface under WEDM machining process there is a new methodology discussed in [2]. Moreover, this material withstands for long duration and durable. These are last for more than 20 years when inserted in the body in the form of titanium cages, pins, plates and rods. [3] illustrated the benefits of Titanium non-ferromagnetic property which allows patients with titanium implants to be safely examined with MRIs and NMRIs. Because the titanium acts as perfect joint with bone, immune from corrosion, flexible, compatible and strong with the growth of bone, from the past decades, these are highly applicable in medical and bio-medical areas. Titanium is applied in various medical fields such as hip, dental implants, and knee replacement treatments, surgical instruments and external prostheses [4]. During WEDM process wire electrode types, characteristics and their recent improvements are discussed [5]. The experiments were conducted on WEDM to determine how the process parameters change performance of machining like cutting rate, surface roughness, and gas current for titanium [6]. The depth of damaged layer in the surface of pure titanium grade 4 and Ti-6Al-4V (grade 5), and the corrosion rate influences was investigated on WEDM [7]. Using Taguchi methodology, the optimal parameters for of titanium alloys surface finish in WEDM were determined [8].

Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Thus, titanium and its alloys are classified as "difficult to machine '' materials Therefore, unconventional machining processes are introduced for machining titanium and its alloys [9] There is some limitation for titanium use because of its initial high cost, availability, inherent properties and manufacturability [10].

2. Technical Specifications

Table 1: Wire cut EDM Machine specifications

Main axes traverse (X, Y)	0.400x0.300 m
Aux. axes traverse (u, v)	0.100x0.100 m
Work table size	0.680x0.500 m
Max. taper angle	0.350 / 0.050m
Max. work piece height	0.2m
Max. work piece weight	0.500Ton
Resolution	0.0005mm
Max. wire spool capacity	8kg (16-45 kg optional
Wire electrode diameter	0.25mm (standard)
Wire spool size	DIN 125, DIN 160, P-3-R, P-5-R

2.1 Work piece Material

Titanium is a metal with excellent corrosion resistance, fatigue resistance, a high strength-to weight ratio that is maintained at elevated temperature. Titanium is a very strong and light metal. This property causes that titanium has the highest strength-to-weight ratio in comparison the other metal that are studied to medical use. Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Thus, titanium and its alloys are classified as difficult-to-machine materials. Therefore, unconventional machining processes are introduced for machining titanium and its alloys. An alpha-beta type titanium alloy (Ti- 6Al-4V) has been selected as work material for this present study.

Table 2: Chemical Composition of Material

C	Fe	N	O	A	V	H	Ti
0.08	0.25	0.05	0.2%	6.76%	4.5%	0.15%	

Figure-1: Work Piece Before & After Machining

2.2 Electrode

Wires with high zinc content make a better EDM electrode but EDM wire with zinc percentages approaching 40% are difficult to produce, so a special method of producing wire with a higher zinc surface has been devised. A heavy coating of pure zinc is applied to the outer surface (18-35μm) of a copper or brass core.

3. Selection of Input Process Parameter

Pulse on Time: The pulse on time is referred as Ton and it represents the duration of time in micro seconds, μs, for which the current is flowing in each cycle. During this time the voltage, VP, is applied across the electrodes. The Ton setting time range available on the machine tool is 100-120, starting from 114 which is applied in steps of 1unit to 116.

Pulse off Time: The pulse off time is referred as Toff and it represents the duration of time in micro seconds, μs, between the two simultaneous sparks. The voltage is absent during this part of the cycle. The Toff setting time range available on the machine tool is 50 - 63 which is applied in steps of 2 units from 56 to 60.

Peak Current: The peak current is represented by IP and it is the maximum value of the current passing through the electrodes for the given pulse. The IP setting current range available on the present WEDM machine is 10–12 ampere which is applied in steps of 1 ampere.
Wire Feed: Wire feed is the rate at which the wire-electrode travels along the wire guide path and is fed continuously for sparking. The wire feed range on the present WEDM machine is 5–15 mm/min in steps of 1mm/min from 5 to 7. It is always desirable to set the wire feed to maximum. This will result in less wire breakage, better machining stability and slightly more cutting speed

Servo Voltage: The MRR increases with increase in servo voltage and then it starts to decrease. This is due to increases in servo voltage results in higher discharge energy per spark because of large ionization of dielectric between working gap. The servo voltage range from 1-30V whereas applied from 1 to 3V with a step of 1V.

3.1 Measurement of Output Responses

Material Removal Rate: In EDM the metal is removed from both the workpiece and the tool electrode. The material removal rate depends not only on the workpiece material but on the material of the tool electrode and the machining variables such as pulse conditions, electrode polarity and the machining medium. In this regard a material of low melting point has a high metal removal rate and hence a rougher surface. Typical removal rates range from 0.1 to 400 mm3 /min. MRR=(Cutting Rate)* (Kerf)* (Thickness of Workpiece) -- mm^3/min

Kerf: Kerf is defined as the width of material that is removed by a cutting process. It was originally used to describe how much material was removed by a tool. In case of CNC cutting, kerf is the width of material that the process removes as it cuts through the plate. Each cutting process removes a different amount of material or kerf. The more precise processes remove a smaller amount of kerf, which is one of the reasons they can be more precise. Digital Vernier Caliper is used to measure Kerf width in mm.

Surface Roughness: One of a good predictor of Wire EDM performance is surface roughness because nucleation sites can be formed for cracks or corrosion by irregularity in the surface. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form.

4. Experimental Design Methodology:

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analysed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed. There are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed. The advantages of design of experiments are as follows:

4.1 Experimentation and data collection

The experiment is performed against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply (if outer array is not used) or according to the outer array (if used). Randomization should be carried to reduce bias in the experiment. The data (raw data) are recorded against each trial condition and S/N ratios of the repeated data points are calculated and recorded against each trial condition.

Table 3: Experimental Design

Exp No.	V	C	T_{0n}	T_{0ff}	w_f
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	2	3	1
11	2	1	2	3	2
12	2	1	2	3	3

13	2	2	3	1	1
14	2	2	3	1	2
15	2	2	3	1	3
16	2	3	1	2	1
17	2	3	1	2	2
18	2	3	1	2	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

Table 4: Input parameters levels

Levels	**1**	**2**	**3**	**Units**
Voltage (V) in Volts	10	13	16	Volts
Current (C) in AMPS	1-2	1-1	1	AMPs
Pulse on time (PO) in µs	1-14	1-15	1-16	µs(coded)
Pulse off time (PF) in µs	56	58	60	µs
Wire Feed(W) in mm/min	5	6	7	Mm/min

Table 5: Experimental Results

Exp No	**MRR**	**KERF**	**SR**
1	7.3872	0.53	0.366
2	7.4308	0.46	3.255
3	8.1838	0.53	1.396
4	4.5481	0.27	1.507
5	5.1672	0.39	3.257
6	3.7733	0.28	2.261
7	4.5818	0.40	2.929
8	4.2329	0.30	2.474
9	5.25	0.45	2.184
10	7.3173	0.41	1.914
11	5.1852	0.40	1.808
12	6.1220	0.43	2.456
13	5.9248	0.45	3.604
14	5.4783	0.44	2.398
15	5.8064	0.40	2.261
16	11.0899	0.47	2.197
17	5.9804	0.29	3.633
18	7.7143	0.51	2.230
19	8.1649	0.44	3.184

20	4.6993	0.32	2.707
21	7.4448	0.53	2.665
22	6.2432	0.44	2.058
23	7.6670	0.53	1.978
24	7.1879	0.51	1.673
25	7.4461	0.51	2.476
26	6.0990	0.44	1.889
27	7.5244	0.55	2.130

Table 6: Analysis of Variance for Material Removal Rate (MRR)

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Voltage (V)	2	9.143	9.143	4.571	3.62	0.050
Current (C)	2	6.402	6.402	3.201	2.54	0.110
Pulse on time (PO)	2	20.313	20.313	10.156	8.05	0.004*
Pulse off time (PF)	2	3.201	3.201	1.600	1.27	0.308
Wire Feed(W)	2	6.646	6.646	3.323	2.63	0.103
Error	16	20.181	20.181	1.261		
Total	26	65.885				

Form the above ANOVA tables it was found that machining servo reference voltage, peak current , pulse off time and wire feed rate are non-significant process parameters for material removal rate because their P-value is more than 0.05. It is concluded from the ANOVA that pulse on time significantly affects the variation in the MRR.

Table 7: Analysis of Variance for Material Removal Rate (KERF)

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Voltage (V)	2	0.02565	0.02565	0.01282	3.18	0.069
Current (C)	2	0.00654	0.00654	0.00327	0.81	0.462
Pulse on time (PO)	2	0.02378	0.02378	0.01189	2.95	0.081
Pulse off time (PF)	2	0.03654	0.03654	0.01827	4.53	0.028*
Wire Feed(W)	2	0.021474	0.021474	0.010737	2.66	0.100
Error	16	0.064526	0.064526	0.004033		
Total	26	0.178519				

Form the above ANOVA tables it was found that machining servo reference voltage, peak current , pulse on time and wire feed rate are non-significant process parameters for kerf because their P-value is more than 0.05. It is concluded from the ANOVA that pulse off time significantly affect the variation in the kerf.

Table 8: Analysis of Variance for Material Removal Rate (SR)

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Voltage (V)	2	0.4651	0.4651	0.2326	0.46	0.642
Current (C)	2	0.3178	0.3178	0.1589	0.31	0.737
Pulse on time (PO)	2	2.0215	2.0215	1.0108	1.98	0.171**
Pulse off time (PF)	2	1.2000	1.2000	0.6000	1.18	0.334

Wire Feed(W)	2	1.0420	1.0420	0.5210	1.02	0.383
Error	16	8.1694	8.1694	0.5106		
Total	26	13.215				

Form the above ANOVA tables it was found that machining servo reference voltage, peak current , pulse off time and wire feed rate are non-significant process parameters for surface roughness because their P-value is more than 0.05. It is concluded from the ANOVA that pulse on time significantly affect the variation in the surface roughness.

5. Conclusions:

In this study, various machining conditions were investigated to determine the effect of process parameters on the process responses (Material Removal Rate, Kerf and surface roughness. MRR is greatly affected by TON than other factors and is less affected by TOFF according to ANOVA. For a given range, MRR is maximum at TON = 1-14 µs. According to ANOVA, there are no factors which greatly affect the Surface Roughness whereas TON may moderately affect it and IP will have almost no affect, Within a given range, SR is minimum at TON = 1-15 µs. Kerf width is likely to obtain for TOFF at 58µs,Kerf width is not likely affected by peak current. If only out parameter is required then this analysis helps us much to meet the requirement in the selected range.

6. References

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